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In vivo and in vitro CT analysis of the occiput

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Abstract Arguments concerning the best procedure for occipito-cervical fusion have rarely been based upon occipital bone thickness or only based on in vitro studies. To close this gap and to offer an outlook on preoperative evaluation of the patient, 28 patients were analysed in vivo by means of spiral CT. Ten macerated human skulls were measured by means of CT and directly. Measurements were taken according to a matrix of 66 points following a grid with 1 cm spacing based upon McRae's line. Maximum thickness in the patient group was met 4 cm above the reference plane in the median slice (11.87 mm; SD 3.41 mm) and 5 cm above it in the skull group (15.85 mm; SD 1.81 mm). Correlation between CT and direct measurements was good (91.79%). Intra-individual discrepancies from one side to the respective point on the other

side are common (difference > 1 mm in 60%). Judging areas suitable for operative fixation using the 10% percentile value (6.68 mm for the maximum value of 11.87 mm) led to the conclusion that screws should only be inserted along the occipital crest in an area extending from 1.5 cm above the posterior margin of the foramen magnum to the external occipital protuberance (EOP). At the level of the EOP screws may also be inserted up to 1 cm lateral of the midline. A reduction of screw length to 7 mm (9 mm for the EOP) is proposed. Preoperative evaluation of the patient should be carried out by spiral CT with 1 mm slicing and sagittal reconstructions.

Key words Occipito-cervical fusion · Bone thickness · Spiral CT · Skull morphology

Introduction

Occipito-cervical fusion was first described in 1927 by the German neurologist Otfried Förster [11]. Since then a continuously increasing number of studies concerning methods of occipital fusion has been published. The indication in common is an instability at the cranio-cervical junction, which may result in neural symptoms, which are the final indication for operation. The aim of all operative techniques is to reduce this instability, which otherwise may even end up in sudden death [24, 30].

A large number of techniques for occipito-cervical fusion have been described. These can be divided in three

groups: (1) simple onlay techniques [4, 8, 10, 31], (2) wiring techniques [1, 13, 16, 20, 21, 29, 45] and (3) hook and rod [5, 9, 24, 26, 28, 35, 37, 40] or plate [2, 14, 17, 19, 22, 36, 38, 39, 43, 44] fixation. All these methods can be combined with the use of polymethylmethacrylate. In recent years the techniques of the third group have become widely accepted as the gold standard [14, 17, 38]. They require an operative intervention at the occipital bone, either in the form of creating burr holes or in the form of inserting screws.

Besides anatomical considerations for the prevention of complications (e.g. perforation of the venous sinuses), it seems plausible to choose the points for intervention on

Fig. 1 A, B Construction of the measurement distances. **A** Positioning of the slices. The first slice is always set in the midline ('median slice') along the orientation points of the nasion, vomer, mid-point between the ossa petrosa, and the occipital protuberance. The following slices are positioned at intervals of 1 cm from medial to lateral, five on each side ('left 1, left 2, left 3' ...). **B** Positioning of the planes. Example for construction of the planes in the median slice. The dotted lines are construction lines. All planes intersect McRae's line at a 45° angle. Space between two planes is always 1 cm

the bone with regard to bone thickness to guarantee minimum risk of complications arising from perforation of the bone and maximum stability of the instrumentation. Whereas the number of papers dealing with occipito-cervical fusion, its technique and its clinical outcome is immense, arguments for special points of fixation taking into account occipital morphology are very scarce. This aspect is in most cases only dealt with marginally, if at all. The intention of this article is to close this gap and offer an outlook on the preoperative evaluation of the patient.

Materials and methods

The study consists of two parts. In the first part, ten macerated skulls from the Department of Anatomy of the University of Erlangen were analysed (direct bone measurement and CT), nine of which were prepared at an occipito-frontally orientated section line and one was divided into two halves sagittally at the median plane. In the second part, 28 patients were measured by means of CT. The patients had not undergone any preselection except fulfilling the criterion of an age over 15, which was applied to ensure an already finished growth of the skull. The age of the patients ranged from 16 to 93, with one focus between 16 and 21 and otherwise equal distribution of age. Sixteen patients were female, 12 male. The CT measurements were taken with spiral CT, with a slice thickness of either 2.0 or 1.0 mm. Comparing one row of measurements, no relevant influence of this variation in slice thickness on the results could be found. The literature underlines the fact that the projection of anatomical structures increases with decreasing slice thickness, but reaches a sufficient accuracy at a certain point [12, 23, 25, 32, 41]. For the skulls, the window was set higher than 3000 HU (Hounsfield units), the centre between 0 and 80. For the

patients, the window was kept steadily on 2000, the centre on 200. These settings are adequate for providing correct results [23]. In both groups the scanned area reached from a little below the foramen magnum up to an area parallel to the horizontal plane about 2½ cm above the processus clinoidei of the hypophyseal saddle.

Multipanar reconstructions of these scans were produced. A measurement grid with 1 cm spacing was built containing 66 measurement distances (11 slices each in six planes; see Fig. 1). As a reference construction plane containing no measurement points, a plane crossing McRae's line in the median slice at the point of the posterior margin of the foramen magnum at a 45° angle (viewed from dorso-plantar) was used. This system produces clinically more relevant values than the strictly perpendicular measurements of *in vitro* studies, because it measures according to the insertion angle of screws intraoperatively, which is practically more easily kept constant than is a perpendicular orientation. The most caudal plane was designated 'plane 1', continuing cranially to the next plane 'plane 2', and so on. The slices were numbered depending on the distance in centimetres from the midline to the lateral slices (e.g. 'left 3' is the slice 3 cm left of the midline).

The direct measurements of the skulls were taken with a construction that fixes a skull by entering both meatus acustici externi. Along this axis the same 45° angle as in the CT can be set, and the skull, positioned with open skull cavity downwards, can be reached with calipers. The accuracy of this method of measurement was restricted to 0.5 mm only, which might seem little at first sight, but which is justified by the fact that the accuracy of a study is defined by the most inexact variable, which in this case is the CT scan. Even with a slice thickness of 1.0 mm and spiral CT it is impossible to define the border between bone and tissue with an accuracy of more than 0.5 mm.

Results

The results of the skull CT measurements are shown in Fig. 2. The occipital bone was thickest at plane 5 in the median slice, measuring an average of 15.85 mm (SD 1.81 mm, range 6–30 mm) (the higher value at plane 6/slice left 1 can be ignored because of an insignificant number of measurements at this point). It can also be clearly seen that throughout all planes the highest value can generally be found in the median slice. The distinct relative increase of values in the most lateral slices is more an artefact caused by projection than by real bone

Fig. 2 Skull CT measurement: thickness profile. The highest values are to be found along the occipital crest and up to 1.5 cm lateral of the midline in the region of the external occipital protuberance (EOP). The high values in the lateral slices are due to projectional artefacts (see text). Note the low values around the fossa cerebellaris

thickness (see Fig. 2). The distances measured in these lateral areas are more a bone 'length' than a bone thickness, because the more lateral one goes, the more tangentially the skull is crossed by the slices due to the outward-forward curving of the skull. The upward-forward curving of the skull does not affect the reliability of the measurement values, because it reaches a significant curvature just above the area of fixation.

To be able to judge the accuracy of CT for measuring the bone thickness, the values of the CT skull measurements were compared to the direct bone measurements. The statistical analysis showed an average correlation of 0.90 (more precisely 0.90163) (note that this factor is not a proportional corrective factor but only states the accuracy of the method). To establish the nature of this coherence the differences between the CT values and the respective direct bone measurement values were calculated. Analysing the amount and direction (positive or negative) of these differences by means of cumulative frequencies revealed that CT tends to enlarge values, especially in the lower planes with little thickness. This effect has already been reported in literature and is assessed with different values for the magnitude of the effect [27, 42]. On the other hand the analysis showed that in more than 80% of all cases the absolute difference between the direct and the CT measurement was in the range 0–1 mm and in only 7% of the cases was the difference larger than 1.5 mm. So, despite a small tendency to enlargement, the CT method we used can well be taken as a sufficiently exact projection of anatomical reality.

The results of the patients' scans are shown in Fig. 3 and Table 1. The occipital bone is thickest at plane 4 in the midline (11.87 mm; SD 3.41 mm; range 5.3–17.1 mm).

Fig. 3 Mean values measured on patient scans (based on the data presented in Table 1). As with the in vitro measurements, the highest values are to be found along the midline. The distribution of thickness is nearly identical to the skull group (Fig. 2)

Table 1 Mean value of the thickness measurements taken from patient scans, in millimetres. The maximum value can be found at plane 4 in the median slice

Slice	Plane 1	Plane 2	Plane 3	Plane 4	Plane 5	Plane 6
Left 5	6.08	7.05	8.89	8.38	9.44	8.75
Left 4	3.48	4.96	6.68	7.92	7.72	10.09
Left 3	2.39	3.54	5.23	6.67	7.11	8.11
Left 2	2.72	3.73	4.65	6.43	6.57	6.6
Left 1	3.67	3.84	5.15	8.07	8.02	7.11
Median	6.58	8.29	10.01	11.87	10.67	9.76
Right 1	3.27	3.7	5.41	8.48	9.19	8.09
Right 2	2.39	3.09	4.43	6.65	7.44	6.9
Right 3	2.39	3.59	5.12	6.82	7.13	8.12
Right 4	3.88	4.95	7.2	8.22	7.59	8.66
Right 5	5.53	6.59	9.16	8.16	9.76	11.8

Gender differences were investigated, but despite a trifling tendency of higher values in the male group no statistically significant gender difference could be found contrary to the findings of Ebraheim et al. [7]. To check the reliability of the results, the values of the left side and the corresponding right side were compared based upon the supposition of symmetry of the human skeletal construction according to two criteria (difference of ranking > 4 and absolute difference > 0.5 mm). Discrepancies according to these criteria were found in six pairs (i.e. 9%). As two of these six pairs belong to utmost lateral slices of plane 6, the supposition of symmetry confirms the results. Whereas the average values agreed well (90% to within 0.5 mm), intraindividual differences, which were examined by cumulative frequencies of the left to right difference, regularly showed considerable divergence. As can be ex-

Table 2 The 10% percentile values of the measurements shown in Table 1. These are the values exceeded by 90% of the patients and thus are relatively safe values. Statistically reliable thickness of more than 5 mm can only be found in the midline and in a small area around the median slice in plane 4

Slice	Plane 1	Plane 2	Plane 3	Plane 4	Plane 5	Plane 6
Left 5	3.32	3.7	6.3	4.8	5.55	6.3
Left 4	2.04	3.18	3.8	5.44	5.22	5.91
Left 3	1.3	2.37	3.48	4.37	4.1	5.12
Left 2	1.46	1.99	2.78	4.26	4	4.22
Left 1	1.9	2.1	2.68	5.06	3.35	4.14
Median	4.68	4.77	6.41	6.68	5.71	6.62
Right 1	1.46	2.08	2.5	5.64	6.08	4.74
Right 2	1.3	1.49	2.37	4.63	4.65	4.74
Right 3	1.3	1.9	2.46	4.19	4.21	5.1
Right 4	2.1	2.69	4.07	5.45	4.98	5.1
Right 5	2.73	3.69	4.8	5.39	5.92	7.3

pected the dimension of this divergence in absolute numbers is still small in plane 1. In the more cranial planes, however, the values of the two sides varied by less than 1 mm in only 40% of the patients. Moreover, in 25% of the patients there was a divergence of more than 2 mm between corresponding slices, and in 10% of the patients this divergence was more than 3 mm.

Table 2 shows the 10% percentile values for the patients' measurements. The percentiles are of interest in the context of maximum safe screw length, because they show the value that is exceeded by 90% of the patients.

Discussion

Papers dealing with occipital morphology are rare. In most reports stating facts about occipital bone thickness, information is vague and no detailed study design for the measurements can be found. There are carefully conducted studies [7, 46], but they are only in vitro studies. The present in vitro *and* in vivo study offers directly transferable data for clinical use. Table 3 offers a survey on previously published values of occipital bone thickness.

The results of the current study can, therefore, be included among the reference literature. Astonishingly, the results of the studies mentioned above diverge remarkably, despite claiming comparable accuracy. The maximum value for thickness at the EOP measured by Heywood et al. [22] lies even below the mean value found by Zipnick et al. [46]. This shows that results are extremely dependent on study conditions, especially on the measurement angle. This emphasises the need for thickness measurements relevant for practice to be taken according to the angle applied intraoperatively for the insertion of screws or other material for fixation (see Materials and methods). Whereas the pattern of ranking for the measurement locations according to thickness was widely identical for the patients and the skulls in this study, there was a considerable difference in absolute values (mean 20%). De Clerck et al. [6] advised that the value of measurements at the human skull must be judged taking into account the alterations the skull may undergo (e.g. during macerating processes).

The areas for operative intervention in occipito-cervical fusion described in the literature are spread all over the

Table 3 Published values concerning occipital bone thickness (according to literature [3, 33] the external occipital protuberance, *EOP*, is an inconstant point, which can be found at about 4.5 cm from the posterior margin of the EOP)

Author	Location	Thickness
Grantham et al. [19]	From foramen magnum to the region of the EOP	Average of 7 mm
Castaing et al. [3]	1 cm below the EOP	13 mm (range 10–20 mm)
Grob et al. [18]	At the level of the superior nuchal line	
	In the median line	14.03 mm
	Paramedian left in the projection of the alignment of the cervical joints	5.71 mm
	Paramedian right in the projection of the alignment of the cervical joints	6.63 mm
Heywood et al. [22]	Cerebellar fossa	3–5 mm
	Around the foramen magnum	< 9 mm
	EOP	11–17 mm
	20 mm from the foramen magnum up to the EOP in the midline	> 9 mm
Olivier [33]	EOP	14.79 mm (SD 2.94 mm)
Zipnick et al. [46]	EOP	17.55 mm (SD 3.18 mm)
Ebraheim et al. [7]	EOP	♂ 15.1 mm (SD 2.6 mm)
		♀ 12.0 mm (SD 1.9 mm)
Present study	Plane 4/median slice	Patients: 11.87 mm (SD 3.41 mm)
	Plane 5/median slice	Skulls: 14.30 mm (SD 2.54 mm)

Table 4 Published values concerning screw length

Author	Location	Screw length
Gros et al. [19]	Median crest	12–14 mm
Castaing et al. [3]	1 cm below EOP	12 mm
Patté and Rose [34]	Paramedian left and right of the median crest	12 mm
Grob et al. [15]	Median crest	10–12 mm
Stecken et al. [44]	Paramedian left and right of the median crest	10 mm
Heywood et al. [22]	EOP and paramedian left and right of the EOP	8–10 mm
Ebraheim et al. [7]	EOP	10–12 mm
	Paramedian left and right of the EOP	8 mm
Smith et al. [43]	Paramedian left and right of the median crest	6–8 mm
Present study	EOP region (plane 4/5)	9 mm
	Occipital crest	7 mm
	Paramedian in plane 4/5	7 mm

Fig. 4 The dotted area shows the region suitable for screw insertion. It stretches from 1.5 cm above the posterior margin of the foramen magnum to the region of the EOP

occiput. According to the authors, rod-and-wire techniques normally require several, sometimes very large, burr holes. Moreover, they are often placed into the region of the fossa cerebellaris [5, 9, 24, 28], where the bone offers a thickness of only about 3 mm (see Fig. 3 and Table 1). Taking into account the fact that this thin plate of bone is getting pierced almost like a sieve (e.g. five holes with a total base of six cm² [24]), these techniques can not be recommended from the standpoint of the analysis of occipital bone thickness. Nevertheless, it has to be mentioned that the authors of these techniques also report very few complications. There are two possible techniques for plate fixation. While some authors prefer median fixation [17, 19, 22], others propose paramedian screw insertion [38, 43]. To these paramedian constructions similar principles must be applied as to the rod-and-wire techniques. They lie, at least partially, in the area of very thin bone formation. Based upon the results of the CT measurements of the patients, fixation along the midline thus

seems favourable. In this procedure the best compromise has to be met between approaching the foramen magnum too closely, where the mean values of bone thickness already decrease markedly (safety distance recommended, 1.5 cm) and cranial transgression of the EOP implicating the danger of affecting the transverse sinuses or the confluens sinuum [3, 7, 22].

Whatever the operative procedure, there is no screw length commonly agreed on by the different authors. Table 4 shows different proposals for screw length. The mean values in Table 1 could indicate a screw length of 10–12 mm for the area of EOP. However, the mean value seems to be an inadequate standard for estimating screw length, because the screw length ought to offer safety even if skulls lie in the lower area of the standard. The 10% percentiles (see Table 2) give a more appropriate scale. Adding to these values the thickness of commonly used plates (2–2.5 mm according to producer) leads to the conclusion that, especially as most authors advise unicortical purchase only [7, 22, 46], screw length should be reduced to 9 mm for the area of the EOP and to 7 mm for the occipital crest, respectively the paramedian areas in planes 4 and 5. Screw insertion lateral of the midline should be avoided in planes 1–3 from the viewpoint of thickness analysis. Figure 4 shows the resulting suitable area for fixation. Taking into account the thickness analysis of the occiput and the reference literature, a synthesis of a T-plate and a Y-plate ('TY-hybrid') would seem to be the ideal implant.

Nonetheless, the results of morphometric studies can not dispense with the necessity of preoperative staging in every patient. On the one hand there is considerable individual variability – standard deviations up to 57% of the mean value can be found. Even in the areas preferable for fixation, the range of values lies barely below 10 mm. In addition, the immense intra-individual variability shows the impossibility of classifying patients by means of isolated marks. On the other hand, patients with tumours or osteoporotic changes may show pathological malformation with partial destruction of the bone structure (e.g. Fig. 5), which requires individual operative planning. A

Fig. 5 Unexpected structural change in a 66-year-old rheumatoid arthritis patient. This female patient, with long history of rheumatoid arthritis shows a cystic structure, in the precise area of plane 4 normally preferable for fixation, that doesn't seem to be connected with the main disease. Occipital fusion without precise preoperative CT may easily lead to bad results in such cases

primary CT scan alone is insufficient, as it's not the horizontal thickness that's decisive but – as already mentioned – the thickness along the insertion angle of the screws. To gain information about this parameter, the use of sagittal secondary reconstructions is very apt. To acquire best pic-

tures (i.e. without discontinuity), scanning with minimal slice thickness is optimal. The experience with the reconstructions used in this study leads us to suggest thin slice technique with 1 mm slicing as standard. As most operations at the cervical spine require preoperative CT anyway, the area scanned for occipito-cervical fusion should be extended a little cranially beyond the EOP. With spiral technique, 1 mm slicing is a simple procedure with a very short examination time for the patient (less than 1 min).

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